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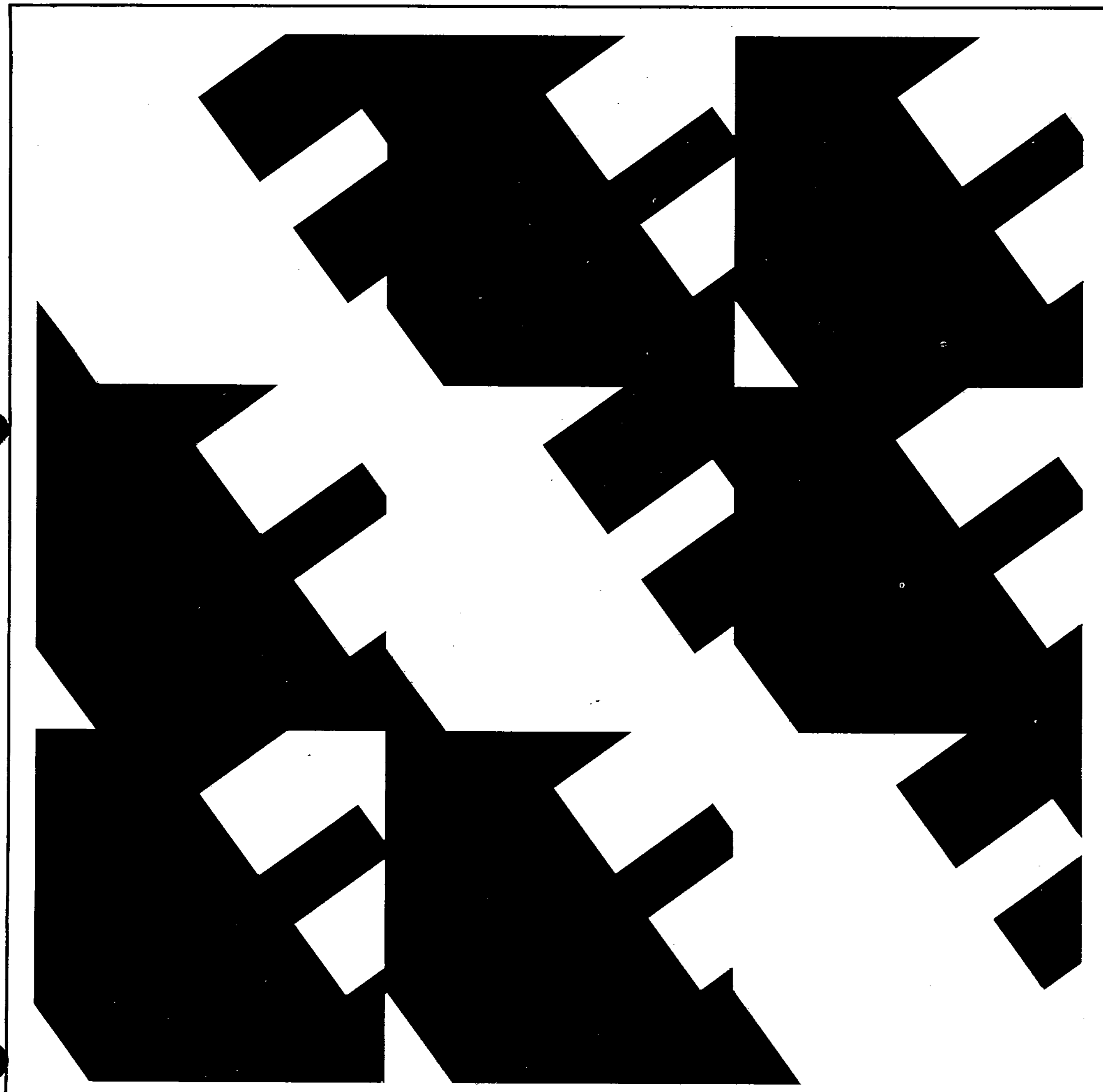
ANSI/IEEE Std 469-1988
(Revision of IEEE Std 469-1977)

IEEE Recommended Practice for Voice-Frequency Electrical-Noise Tests of Distribution Transformers



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(Revision of IEEE
Std 469-1977)

An American National Standard

IEEE Recommended Practice for Voice-Frequency Electrical-Noise Tests of Distribution Transformers

Sponsor

**Transmission Systems Committee
of the
IEEE Communications Society**

Approved June 9, 1988

IEEE Standards Board

Approved September 26, 1988

American National Standards Institute

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Foreword

(This Foreword is not a part of ANSI/IEEE Std 469-1988, IEEE Recommended Practice for Voice-Frequency Electrical-Noise Tests of Distribution Transformers.)

1977 Issue

There has long been a need to provide standard methods of testing distribution transformers to determine their voice-frequency noise contribution to paralleling communications circuits. In recognition of this fact, the Inductive Coordination and Electrical Protection Subcommittee of the Wire Communication Committee established a working group to research this problem. The personnel of the TIF Objectives Working Group that developed this recommended practice were as follows:

D. H. Potter, *Chairman*

D. M. Anselm
G. Bagnall
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W. B. Wilkens
F. P. Zupa

The working group also wishes to acknowledge the able technical assistance and guidance provided by G. Y. A. Allen. Mr. Allen is Chairman of the Inductive Coordination and Electrical Protection Subcommittee, which has reviewed and approved this guide.

1988 Issue

The 1977 standard has been revised so as to justify the use of secondary circuit excitation measurements, provide the derivation of the constants used in interpreting the measurements, and to provide the rationale for deriving limits. As part of this revision, reference tables are expressed in the form usually used and a number of outdated forms have been dropped. The members of the TIF Objectives Working Group involved with this revision are as follows:

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On June 10, 1987, the ICEP Balloting Committee voted to submit this document to the IEEE Standards Board. The following members were present:

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When the IEEE Standards Board approved this standard on June 9, 1988, it had the following membership:

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An American National Standard

IEEE Recommended Practice for Voice-Frequency Electrical-Noise Tests of Distribution Transformers

1. Introduction and References

1.1 General. The practice described herein provides instruction for the testing of distribution transformers as sources of voice-frequency noise. These tests measure the degree to which a transformer may contribute to electrical noise in communication circuits that are physically paralleling the power-supply circuits feeding the transformer.

Transformers have a characteristic that is common to other iron-core devices of causing harmonic currents at voice frequencies to flow in supply circuits to the transformers. The magnitude of these currents, and of interference that may result, varies according to the design of the transformer as well as the excitation voltage. The tests described in this practice provide a standard method for use by the transformer manufacturer, user, and others in industry for the purpose of better evaluating the design choices that are available and moving toward industry objectives with regard to levels of harmonic exciting current expressed as $I \cdot T$ (current x telephone influence factor [TIF]).

1.2 References. The following publications shall be used in conjunction with this standard.

[1] ANSI/IEEE C57.13-1978 (R1986), IEEE Standard Requirements for Instrument Transformers.[1]

[2] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.

[3] BALL, W. C., and POARCH, C. K. Telephone Influence Factor (TIF) and Its Measurement. *AIEE Trans. Commun. Electron.*, vol 79, Jan 1961, pp 659–664.

[4] *The Telephone Influence Factor of Supply Systems Voltages and Currents.* Joint Subcommittee on Development and Research, Edison Electric Institute and Bell Telephone System, Suppl Engineering Report 33, EEI Publication 60-68, New York, NY, Sep 1960.

2. Definition of Terms

Certain terms that are not widely known have been found to be helpful in measurement and discussion of voice-frequency noise induction in communication circuits. They are as follows.

2.1 Inductive Influence (Electric Supply Circuit With Its Associated Apparatus). Those characteristics that determine the character and the intensity of the inductive field that it produces [2].[2]

Inductive influence is a measure of the interfering effect of the power system.

2.2 *c*-Message Weighting. A weighting derived from listening tests to indicate the relative annoyance or speech impairment by an

[1] ANSI/IEEE publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from the Institute of Electrical and Electronics Engineers, Service Center, Piscataway, NJ 08854-1331.

[2] The numbers in brackets correspond to those of the references listed in 1.2.

Table 1
c-Message Weighting (in dB)

f	P'_f	f	P'_f	f	P'_f
60	55.7	1260	0.4	2580	1.7
180	29.6	1380	0.7	2700	2.2
300	16.5	1500	1.0	2820	2.8
420	10.2	1620	1.3	2940	3.5
540	6.2	1740	1.5	3060	4.4
660	3.3	1860	1.5	3180	5.2
780	1.3	1980	1.5	3300	6.2
900	0.3	2100	1.5	3540	8.4
1000	0.0	2220	1.5	4020	14.7
1020	0.0	2340	1.5	4500	21.8
1140	0.1	2460	1.5	5000	29.5

Table 2
1960 Single-Frequency TIF Weighting

f	W'_f	f	W'_f	f	W'_f
60	0.5	1260	6050	2580	10600
180	30	1380	6370	2700	10480
300	225	1500	6680	2820	10210
420	650	1620	6970	2940	9820
540	1320	1740	7320	3060	9230
660	2260	1860	7820	3180	8740
780	3360	1980	8330	3300	8090
900	4350	2100	8830	3540	6730
1000	5000	2220	9330	4020	3700
1020	5100	2340	9840	4500	1830
1140	5630	2460	10340	5000	840

interfering signal of frequency f as heard through a "500-type" telephone set. The result, called "c-message weighting," is shown in Table 1 [3], [4].

2.3 Telephone Influence Factor. The telephone influence factor (TIF) of a voltage or current wave in an electric supply circuit is the ratio of the square root of the sum of the squares of the weighted root-mean-square values of all the sine-wave components (including, in alternating-current waves, both fundamental and harmonics) to the root-mean-square value (unweighted) of the entire wave [2].

2.3.1 The TIF represents the relative interfering effect of voltages and currents at the various harmonic frequencies that appear in power-supply circuits. It is a dimensionless quantity indicative of waveform and not of amplitude.

2.3.2 TIF takes into consideration the characteristics of the telephone receiver and the ear (all represented by c-message weighting) and the assumption that the coupling between the electric supply circuit and the telephone circuit is directly proportional to the interfering frequency. TIF is also shown as T for convenience and is expressed as

$$T = \left(\Sigma (X_f \cdot W_f)^2\right)^{0.5} \Big/ X_t \qquad \text{(Eq 1)}$$

where

X_t = total effective or rms current (I) or voltage (kV)

X_f = single-frequency effective current (I) or voltage (kV) at frequency f, including the fundamental

W_f = single-frequency TIF weighting at frequency f

2.3.3 The TIF contribution of power-circuit voltage or current at frequency f may be expressed as follows:

$$T_f = (X_f \cdot W_f)/X_t \qquad \text{(Eq 2)}$$

2.3.4 The 1960 TIF weighting characteristic represents the relative interfering effect of a voltage or current in a supply circuit at frequency f. The weighting takes into account the relative subjective effect of frequency f as heard through a telephone set (that is, the c-message weighting) and the coupling between the power and telephone circuit, assumed to be directly proportional to frequency. The 1960 TIF weighting [4] is defined as

$$W'_f = 5P_f \cdot f \qquad \text{(Eq 3)}$$

where

5 = a constant

$$P_f = \text{antilog}\,(-P'_f/20) \qquad \text{(Eq 4)}$$

It is the voltage or current c-message weighting equivalent of the power (dB) weighting of Table 1.

f = frequency under consideration in Hz

The 1960 TIF weighting characteristic is shown in Table 2.

2.4 $I \cdot T$ Product (As Applicable to the Electrical Supply Circuit). The inductive influence usually expressed in terms of the product of its root-mean-square magnitude in amperes (I) times its telephone influence factor (TIF) abbreviated as $I \cdot T$ product [2].

2.4.1 $I_s \cdot T$ Product (As Applicable to Transformers). The $I \cdot T$ product measured in the secondary (low voltage) of a transformer when the primary (high voltage) is open-circuited. It is abbreviated as $I_s \cdot T$.

2.4.2 $I_p \cdot T$ Product (As Applicable to Transformers). The $I \cdot T$ product measured in the primary of a transformer when the secondary is open-circuited. It is abbreviated as $I_p \cdot T$.

2.5 kV·T Product (As Applicable to Inductive Coordination). The inductive influence usually expressed in terms of the product of its root-mean-square magnitude in kilovolts (kV) times its telephone influence factor (TIF), abbreviated as kV·T product [2].

3. Purpose of Tests

3.1 The purpose of these tests is to measure the harmonic currents flowing during the excitation of individual transformers. The corresponding 1960 TIF weightings and root-sum-square calculations are applied to give the $I_s \cdot T$ or $I_p \cdot T$ values. The $I_s \cdot T$ or $I_p \cdot T$ values are then normalized by dividing them by the kVA rating of the transformer. These figures are considered to be a measure of noise-producing influence of the transformer.

3.2 The kV·T product is measured at the energized terminals of the transformer under test. The kV·T product is a measure of the quality of the power-supply. The kV·T levels must be within stated bounds to minimize testing errors.

3.3 The harmonic distortion produced by transformers originates in the nonlinear magnetic characteristics of the core material. For typical sinusoidal excitation voltages the excitation current peaks produce magnetic flux that approaches the saturation of the core. Saturation effects lower the effective impedance of the winding increasing the peak currents beyond those of a sinusoidal one. The excess peak currents increase as the applied excitation voltage increases and the harmonics it contains can be appreciable.

The harmonic currents flow in the power distribution circuits feeding the transformer. These lines frequently run parallel to communication circuits and are loosely coupled to them magnetically. Because of the length of this coupling the harmonic currents can induce significant noise voltages at voice frequencies into the communication lines. These in turn may produce noise currents.

Where the supply voltage remains constant, the generation of harmonic currents by the transformer is almost independent of the load on the secondary of the transformer. Because of this fact transformers can be tested for harmonic generation with open secondary circuits. Usually they are evaluated using 110% of normal excitation voltage. This ensures satisfactory control of harmonics up to this level.

Distribution transformers can be excited from either their high-voltage or low-voltage winding. As long as the harmonic measurements are expressed as the ratio of a specific harmonic current level to that of the actual excitation current level, results using either winding will be the same.

The measurement of harmonic generation requires a 60 Hz voltage source essentially free of harmonics. Low-voltage regulated ac sources are generally less expensive and require fewer safe guards than higher voltage sources. Because of this constraint the measurement of transformer harmonics is generally carried out by exciting the low-voltage winding and expressing the results in terms of a ratio with the effective excitation current.

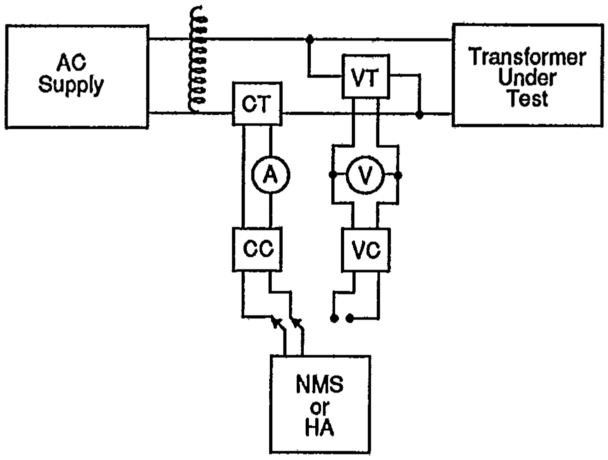
This recommended practice uses the root sum square of all the weighted harmonics divided by the effective excitation current to get a term called "telephone influence factor," or "TIF." The actual noise influence level is obtained by multiplying the TIF by the transformer primary excitation current. This product is called "$I \cdot T$" or "$I \cdot T$ product."

It also gives design specifications for equipment that can directly measure the two components of the ratio TIF and shows how to calculate TIF using specific harmonic measurements.

4. Test Facilities

A recommended test configuration for assessing the $I_s \cdot T$ of distribution transformers is given in Fig 1. The kV·T product is also measured by this circuit to ensure that the ac supply harmonic level does not influence the results.

The circuit consists of a special ac supply with low harmonic content, the transformer under test (driven from a secondary winding with all others open), and the measurement instrumentation.



CT = current transformer
VT = voltage transfomer
CC = current coupler
VC = voltage coupler
NMS = noise measuring set
HA = harmonic analyzer

Fig 1
Typical Test Configuration

4.1 Power Source

4.1.1 An ac power supply is required that has adequate capacity to drive the transformer. Its output must be variable to allow for operation at 110% of rated transformer voltage.

4.1.2 The power supply shall be regulated so as to condition the output. The ac output regulation under load variation shall be 0.03% or better. The output distortion shall be 0.2% or less.

4.1.3 It is recommended that a variable voltage transformer be used as a buffer between the ac supply and the rest of the test circuit to limit surge currents. Under test procedures the applied ac can be raised slowly from 0 V to the test value. For measurements, the variable voltage transformer input and output voltages shall be identical.

4.2 Instrumentation

4.2.1 The currents and voltages to be measured are decoupled from the excitation circuit by means of a current transformer (CT) and a voltage transformer (VT). The recommended ratio of the current transformer is 50:5. It should be capable of reading to 1/100 of an amp. The ratio of the voltage transformer will depend on the transformer under test. Both transformers should conform to ANSI/IEEE C57.13-1978 [1].

4.2.2 The current-coupler in conjunction with the current transformer introduces the frequency dependent factor "f" of Eq 3 required for the TIF weighting.

The recommended current-coupler circuit is given in Fig 2.

When a harmonic analyzer is used, the frequency dependence can be incorporated as part of the calculation (TIF weighting curve). In this case the current coupler L should be replaced by a shunt resistance of approximately 0.20 Ω.

4.2.3 The voltage-coupler introduces the frequency dependent "f" for the voltage TIF and is given by Fig 3.

4.2.4 Metering

4.2.4.1 An rms-reading voltmeter is required to measure X_t for the voltage TIF case.

4.2.4.2 An rms-reading ammeter is required to measure X_t for the current TIF case.

4.2.4.3 A noise measuring set (NMS) or a harmonic analyzer (HA) is required.

Typical NMS Specifications:

Input impedance (balanced)	600 Ω
Detector	rms or quasi rms
Weighting	flat or *c*-message
Scale	dB
Reference (0 dBrn)	10^{-12} W at 1000 Hz
Range	0–95 dB

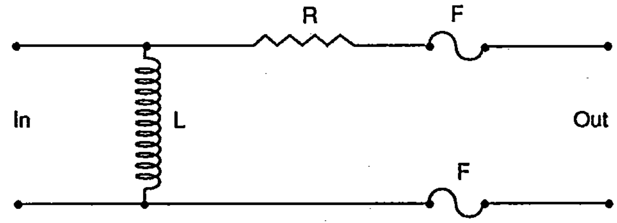
Typical HA Specifications:

Input impedance (balanced)	600 Ω
Frequency range	50 Hz to 5 kHz
Selectivity at −60 dBm	±50 Hz (max)
Reference (0 dBrn)	10^{-12} W
Range	0–95 dB

4.3 Transformer Under Test. The excitation voltage should be connected to a secondary (low-voltage) winding. All other windings should be left open-circuited. All primary (high-voltage) bushings should be insulated.

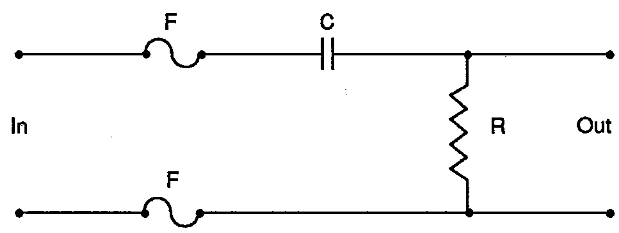
CAUTION: The primary winding is energized to full potential during test. Suitable protective measures such as barriers or insulating blankets and bushing covers should be employed. Grounding of the apparatus should be on the source side of the current coupler or current transformer to avoid error. The transformer tank should be left ungrounded.

4.4 Circuit Evaluation. Tests must be made to establish that the variable voltage transformer, current transformer, voltage transformer, and the current couplers do not affect



R = 600 Ω (including resistance of fuses)
L = 0.4 mH, ≤0.20 Ω resistive
F = 1/8 A

Fig 2
Current-Coupler Circuit



R = 600 Ω
C = 0.01 μFds
F = 1/8 A

Fig 3
Voltage-Coupler Circuit

the waveform under observation. This test should be performed as follows. The test system is configured without the variable voltage transformer, CT and VT. The removal of the variable voltage transformer should be tolerated for this one test. Connect a resistive voltage divider across the transformer terminals with its division ratio chosen so as to produce a level suitable for a harmonic analyzer. Connect the analyzer and determine the $kV \cdot T$ as outlined in 7.3. The voltage TIF should not exceed 5. If this value is not met, it usually means that a higher capacity supply is required. (The value may not be met when very poor transformers are under test.) Reconfigure the circuit as given in Fig 1 leaving the voltage divider and harmonic analyzer connected. Again determine the voltage TIF. It must still be below 5. Use the NMS via the VT and voltage coupler and again determine that the voltage TIF is ≤5, as outlined in 7.1.

5. Measurements

5.1 Connect the source supply, the transformer under test, and the measuring equipment as indicated in Section 4, Fig 1.

5.2 Energize the transformer at rated voltage.

5.3 Set the appropriate weighting available in the equipment used.

5.4 Where an NMS is used, measure and record the $I \cdot T$ product.

5.5 Where an HA is used, measure and record $I \cdot T$ values for each harmonic frequency.

6. Calculation of $I \cdot T$ Results

6.1 Figure 4 shows the equivalent $I \cdot T$ measurement circuit where the component values for the CT were obtained from the typical data curves of ANSI/IEEE C57.13-1978 [1]. For frequencies above about 250 Hz, the load impedance is given by

$$\omega = 2\pi f$$

$$Z_f = 4.0 \cdot 10^{-4} \cdot \omega \qquad \text{(Eq 5)}$$

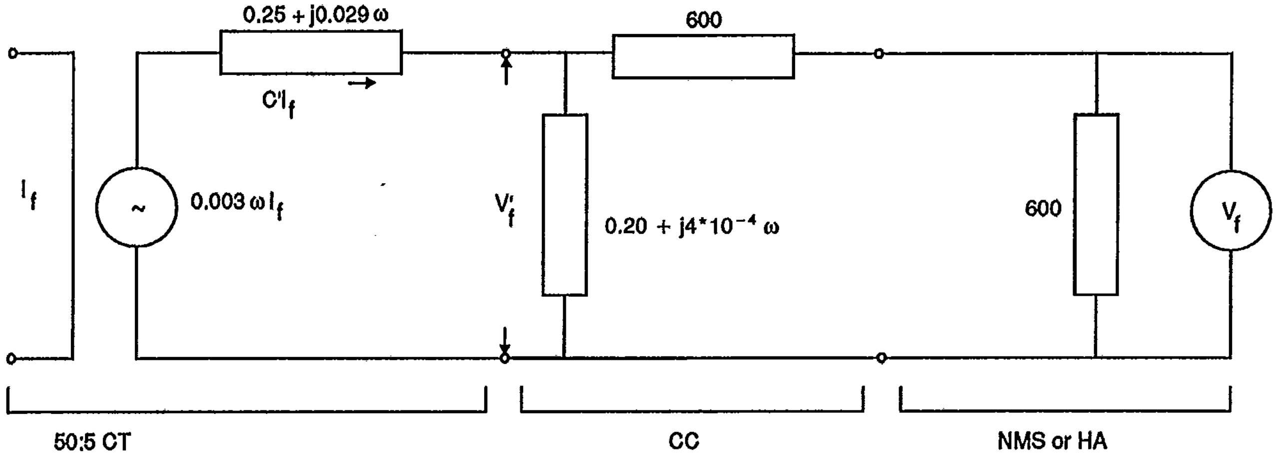


Fig 4
Equivalent $I \cdot T$ Measuring Circuit

The voltage across Z_f is V'_f and is given approximately by

$$V'_f \approx 0.103 \cdot Z_f \cdot I_f \quad \text{(Eq 6)}$$

The factor 0.103 is the current ratio of the CT and will be called C'. The equivalent power ratio C_1 is

$$C_1 = 20 \log (1/C') = 19.7 \text{ dB} \quad \text{(Eq 7)}$$

6.2 A noise measuring set with effective c-message filter and adjusted to 10^{-12} W reference at 1000 Hz has a dB reading N_i in terms of the harmonic voltages V across its 600 Ω input given by

$$N_i = 10 \log \left[\frac{10^{12} \Sigma (V_f \cdot P_f)^2}{600}\right] \text{dBrnc} \quad \text{(Eq 8)}$$

The $I \cdot T$ product for this same case expressed in dB is given by

$$\begin{aligned} 20 \log (I \cdot T) &= 20 \log \left[5\left(\Sigma (I_f \cdot f \cdot P_f)^2\right)^{0.5}\right] \\ &= 20 \log \left[\frac{9.75 \times 10^4}{C'} \left(\frac{\Sigma (V_f \cdot P_f)^2}{600}\right)^{0.5}\right] \\ &= 20 \log \left[\frac{9.75 \times 10^{-2}}{C'}\right] + N_i \\ &= N_i - K_1 + C_1 \\ &= N_i - 0.5 \quad \text{(Eq 9)} \end{aligned}$$

The term $K_1 = 20.2$ dB in this equation is the scale factor for the measurement.

6.3 When an HA is used with the same coupler, and the filter-analyzer combination is adjusted to have a reference of 10^{-12} W at 1000 Hz, then the noise measurement at frequency f is given by

$$N_i = 10 \log \left[\frac{10^{12} (V_f \cdot P_f)^2}{600}\right] \text{dBrn} \quad \text{(Eq 10)}$$

The $I \cdot T$ product in this case is

$$\begin{aligned} 20 \log (I \cdot T) &= 10 \log \left[\Sigma \text{ antilog} \left(\frac{N_f}{10}\right)\right] - K_1 + C_1 \\ &= 10 \log \left[\Sigma \text{ antilog} \left(\frac{N_f}{10}\right)\right] - 0.5 \quad \text{(Eq 11)} \end{aligned}$$

6.4 When the HA does not include a c-message weighting the measurements are called N'_f. The weighting P'_f is obtained from Table 1 and the following equation is used:

$$\begin{aligned} 20 \log (I \cdot t) &= 10 \log \left[\Sigma \text{ antilog} \left(\frac{N'_f - P'_f}{10}\right)\right] - K_1 + C_1 \\ &= 10 \log \left[\Sigma \text{ antilog} \left(\frac{N'_f - P'_f}{10}\right)\right] - 0.5 \quad \text{(Eq 12)} \end{aligned}$$

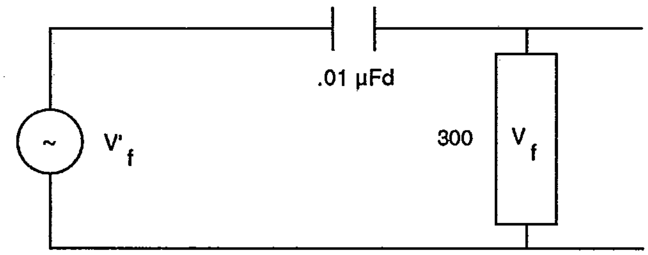


Fig 5
Equivalent $V \cdot T$ Measuring Circuit

6.5 When measurements are to be made on transformers where harmonics below the 5th form the dominant part of the $I \cdot T$ product, the frequency-dependent coupler may not be sufficiently accurate. In these cases a coupler with a flat frequency response should be used, "without a *c*-message filter." The frequency dependence should be introduced by calculation. The measured noise in this case will be N''_f. For a shunt coupling resistance of 0.20 Ω the following may be used:

$$\begin{aligned}
20 \log (I \cdot t) &= 20 \log \left[\left(\Sigma \, (I_f \cdot W'_f)^2 \right)^{0.5} \right] \\
&= 20 \log \left[\frac{122.5 \times 10^{-6}}{C'} \cdot \left(\Sigma \frac{(V''_f \cdot W'_f)^2}{600} \right)^{0.5} \right] \\
&= 10 \log \left[\Sigma \text{ antilog} \left(\frac{N''_f + 20 \log W'_f}{10} \right) \right] - K'_1 + C_1 \\
&= 10 \log \left[\Sigma \text{ antilog} \left(\frac{N''_f + 20 \log W'_f}{10} \right) \right] - 58.5 \qquad \text{(Eq 13)}
\end{aligned}$$

$K' = 78.2$ dB
$W'_f =$ has the values given in Table 2

7. Calculation of kV $\cdot$ T Results

7.1 Figure 5 shows the equivalent voltage coupler kV $\cdot$ T circuit including a VC and NMS or HA where the PT has a 1:1 ratio.

The voltage V_f at the input to the NMS or HA is given in terms of the source voltage V'_f as

$$V_f \approx V'_f \cdot 300 \cdot 0.01 \cdot 10^{-6} \cdot 2\pi f \qquad \text{(Eq 14)}$$

The log of the kV $\cdot$ t product is

$$\begin{aligned}
20 \log (\text{kV} \cdot t) &= 10 \log \left(\Sigma \, (V'_f \cdot W_f)^2 \right) - 60 \\
&= 10 \log \left(\Sigma \, (V'_f \cdot f \cdot 5 \cdot P_f)^2 \right) - 60 \\
&= 10 \log \left(\Sigma \left(\frac{V_f \cdot P_f}{6 \cdot 10^{-6} \cdot \pi} \right)^2 \right) - 46 \\
&= 10 \log \left(\Sigma \, (V_f \cdot P_f)^2 \right) + 48.5 \\
&= N_c - 43.7 \text{ dB} \qquad \text{(Eq 15)}
\end{aligned}$$

where N_c is the *c*-message noise measurement of the NMS in dBrnc. Where the source voltage is 120 V the value of T is given by

$$T = (\text{antilog } ((N_c - 43.7)/20))/0.12 \qquad \text{(Eq 16)}$$

Where the source is 132 V divide by 0.132 instead of 0.12.

7.2 When the source generator may exceed the input voltage rating of the NMS or HA then a VT transformer with a ratio other than 1:1 must be used. When the ratio is less than one, the equivalent expression for the kV $\cdot$ T product is

$$20 \log (\text{kV} \cdot t) = N_c - 43.7 - 20 \log (\text{ratio}) \qquad \text{(Eq 17)}$$

7.3 When calibrating the test circuit an HA should be connected via a voltage divider directly to the source generator. In this case the individual noise readings must be weighted using Table 2 and summed as follows:

$$20 \log (\text{kV} \cdot t) = 10 \log \left[\sum \text{antilog} \left(\frac{N_f - P_f}{10} \right) \right] + 20 \log (\text{ratio}) - 60 \quad \text{(Eq 18)}$$

8. Examples

A 15 kVA transformer with a voltage ratio of 60:1 is to be tested. The circuit is already calibrated, but the voltage TIF should be checked. At 132 V excitation the noise measuring set connected to the voltage coupler indicates a level of 35.7 dBrnc. The VT ratio is 1:1, hence:

$$20 \log (\text{kV} \cdot T) = 35.7 - 43.7$$

$$\text{kV} \cdot T = 0.398$$
$$T = 0.398/0.132 = 3.0$$

This meets the criteria given in 4.4 so measurements may proceed. With excitation of 120 V the NMS with current coupler and *c*-message filter gives 43.6 dBrnc. Using Eq 9:

$$20 \log (I \cdot T) = 43.6 - 20.2 + 19.7 = 43.1 \text{ dB}$$

$$I \cdot T = 142.9$$
$$I \cdot T/\text{kVA} = 9.53$$

The measured value of X_t is 1.15 A. This gives $T = 124.2$.

When the excitation is increased to 132 V the NMS reads 60.9 dBrnc.

$$20 \log (I \cdot T) = 60.9 - 20.2 + 19.7 = 60.4 \text{ dB}$$

$$I \cdot T = 1047$$
$$I \cdot T/\text{kVA} = 69.8$$

The measured values of X_t is 3.80 A. This gives $T = 275.5$.

9. Limit Criteria

9.1 The scope of this standard does not include the setting of limits or objectives for distribution transformers. However, some discussion of limit criteria may be useful.

Ideally, transformer harmonic limits should reflect both the noise requirements of communication systems and transformer manufacturing constraints. Existing limits, however, have been based exclusively on measurements of transformer $I \cdot T$ expressed as $I \cdot T$/kVA. The choice of limits presumably reflected a reasonable manufacturing yield. Communication system noise objectives have not been directly applied. Because of this approach transformer harmonic control is, at best, a process of maintaining the current noise levels.

9.2 Transformer operating excitation currents (primary) can be designed to meet any user requirements, but because of their small amplitudes with respect to the rated current they could be considered roughly proportional to the kVA rating for small transformers. As a result, the term $I_p \cdot T$/kVA is nearly constant and therefore may serve as a useful base for setting harmonic limits.

9.3 The noise-to-ground produced by induction in a communication line is directly proportional to the harmonic earth return current of the power line. For a single transformer load, this earth return current will be proportional to the primary excitation current.

9.4 Both 9.2 and 9.3 imply that $I_p \cdot T$/kVA would be the best term to use as the basis for limits. However this standard measures $I_s \cdot T$. An approximate conversion factor between the two is the voltage ratio primary to secondary (E_p/E_s):

$$I_s \cdot T = I_p \cdot T \cdot E_p/E_s \quad \text{(Eq 19)}$$

9.5 Consider the case where limits for $I_s \cdot T$/kVA have been derived from measurements of small transformers where E_p/E_s equals 60. Reasonable limits under these conditions are[3]: 100% of operating 22, 110% of operating 66. Using Eq 19, an equivalent value is

$$I_p = T/\text{kVA}_{100\%} = 0.37$$

$$I_p = T/\text{kVA}_{110\%} = 1.10 \quad \text{(Eq 20)}$$

These values are independent of kVA rating and of transformer voltage ratio. They can therefore be used to derive limits for other voltage ratios. Table 3 gives this projected set.

[3] Limits supplied by REA, Washington.

Although differing turn ratios will change the $I_p T$/kVA for a given $I_s T$/kVA, there are other application considerations that may make it desirable to maintain constant $I_s T$/kVA limits.

9.6 The general exposure of communication lines to power lines will involve harmonic currents from many distribution transformers. Where these transformers have a distribution of test $I_s \cdot T$/kVA values, then the resultant noise will be due to their average $I_p \cdot T$. For typical tests, the spread in $I_p \cdot T$ is quite large so that the average is low.

From the standpoint of limiting noise a control on the batch average of $I_p \cdot T$/kVA should be considered.

9.7 A group of 9 transformers of mixed kVA and voltage ratio were tested with the results given by Table 4.[4]

Note that the "worst case" results exceed the suggested $I_p \cdot T$ limits of 9.5, but that the mean (batch average) falls below the suggested limit.

9.8 The calculation of absolute noise levels on communication lines due to a specified $I_p \cdot T$/kVA requires knowledge of harmonic phasing on transmission lines. As this is not fully resolved only relative analysis can be made. In general halving the $I_p \cdot T$/kVA level will reduce the noise by 6 dB.

[4] Data supplied by REA and T. Thompson of Ontario Hydro.

Table 3
Reasonable Limits

$I_s \cdot T$/kVA Limits for Indicated Voltage Ratios			
60		120	
100%	110%	100%	110%
22	66	44	132

Table 4
Typical Statistics of $I_p \cdot T$/kVA

	$I_p \cdot T$/kVA		
Operating	Mean	Std. Dev.	Worst Case
100%	0.36	0.097	0.47
110%	1.09	0.396	1.83

9.9 When transformers are dual voltage (primary), then harmonic rating should be specified for both voltage ratios as operating at the lower ratio produces 6 dB more noise.